PASSIVE MICROPUMP FOR MICROFLUIDICS BASED DEVICES

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One of the essential elements of microfluidics is driving liquid flow in microchannels. Device discussed gives a way to pump liquid passively through a microchannel. The present work represents fiber and paper based passive micro-pumping of liquids through microfluidic devices. The porous structure and network of capillaries inside the paper and fiber materials support spontaneous liquid movement. Agarose gel coating is used with paper in order to achieve variations flow rates. The effect of gel concentration on liquid flow is studied. The concept can be used ubiquitously for microfluidics device application. For its low-cost and is feasible to integrate with devices for low resource settings.

Keywords: Microchannel, flow rate wicking

Introduction

Recently there has been extensive research on paper and fiber based microfluidics [1, 2]. Paper and fiber material has been reported as a convenient substrate for plethora of microfluidics applications [3, 4]. One of the essential elements of microfluidics is driving liquid flow in microchannels. Due to scaling effects a large pressure force is required to move fluids and/or suspended particles in microchannels. To move a fluid through microchannels various pumping mechanisms have been proposed in literature. A general classification divides the micropumping based on active and passive methods. Active methods such as electro-kinetic, electroosmotic, syringe pump, thermo pneumatic etc. require external energy/power source. On the other hand, passive methods of micropumping of liquids utilize the surface properties and geometric effects at micro-scales such as capillary induced pumping or manual hand-held-syringe.

While inherent capillary action inside microchannels make one-time flow through the channel, or if the surface is wetting the capillary action will wet the channel spontaneously once but to make the liquid flow continuously some external force is required. Researchers have also proposed an evaporation-based Micropump and they have achieved constant and continuous flow rates of $\sim$100 nl s−1 [5]. Researchers have used paper as the device substrate hence liquid flows automatically, however for other microfluidics platforms external or inbuilt micropumping is required. Since materials with liquid absorption and wicking capabilities have shown huge potential to be used in microfluidics area, various modes to control and vary flow rates have been reported [6-9].

In present work the paper and fiber materials are used that caused a negative pressure generation to attain liquid flow in any microfluidic platform. Advantages offered by proposed method is its simple fabrication and low cost, wide availability of pumping material, ubiquitous use with broad range of flow rates achievable. Passive mode of operation eliminates the external power requirements as well as applicablity to both open and closed channels.

Material preparation and fabrication

Work presented here uses liquid absorbing materials like cotton fiber and cellulose paper to pump liquid through a polydimethylsiloxane (PDMS) elastomer based microchannel. The microchannel was fabricated in PDMS substrate via standard soft-lithography process. For liquid pumping 1 mm x 20 mm wide Whatman filter paper strips were used as wicking substrate. The wicking strips were spin coated with different concentrations i.e. 1, 5 and 10 wt. % of Agarose gel.

The flowrate variations were obtained by varying shape, size and concentration of gel coating on the wicking strips. Different flow rates have been obtained at different concentrations (in wt.%) of the agarose gel. The prepared liquid pumping material was inserted inside the output reservoir directly (Fig.1). Small particles (polystyrene micro-beads) were added in very low concentrations and tracked for flow characterization. The flow was analyzed under optical microscope, the video was captured with a camera and was analyzed using ImageJ software. The method is very simple, cost effective for microfluidics platforms in point of care diagnostics for low resource settings applications.

Experimental Results

Paper and fiber based Micropump carried out a continuous liquid flow through microchannels. Figure 1 depicts the overall scheme of liquid flow through a microchannel. The flow pumping material was inserted in the outlet section of the microchannel. The flow rate can be adjusted from very low to high value by changing the absorbing material type, material makeup/constituents, material geometry, material physical properties, material dimensions, and material assembly as well by devising new combinations of different materials.

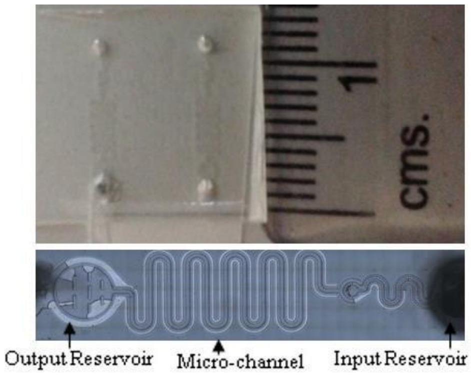

Fig. 1. Flow channel scheme, channel with fiber connected to output reservoir

In this work following methods are used to obtain flow rate variations:

Width of the wicking strips: By increasing the size/diameter of fiber significant flowrate variation was seen. Two sizes 1 mm x 20 cm and 5 mm x 20 cm wide wicking strips were used for conducting liquid flow. The velocity of particles was found to be greater in case of wider wicking strip, Fig. 2. The reason may be availability of higher surface area for wicking of liquid.

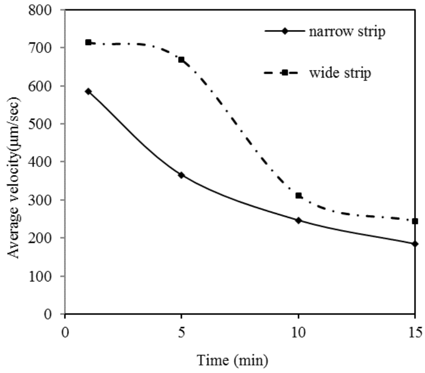

Fig. 2. Effect of width of wicking strip on solution flow

<u>Agarose gel concentration</u>: Agarose gel is a polymer with its constituent molecules connected with abundance of hydrogen bonds. The concentration of gel amounts to the pore size of the gel matrix which plays a crucial role in controlling the liquid flow. Very high flow rates were observed with untreated wicking material. Uniformly suspended polystyrene beads travelling at high speeds, appeared as long streaks during the liquid flow (Fig. 3(a)). With increasing the gel concentrations for the coating the beads travelled at slower rate (Fig. 3 (b)-(d)). This conforms to the potential of using Agarose gel to vary the liquid flow rate through microchannels. Figure 4 represents the average velocity of the tracked polystyrene beads through the microchannel.

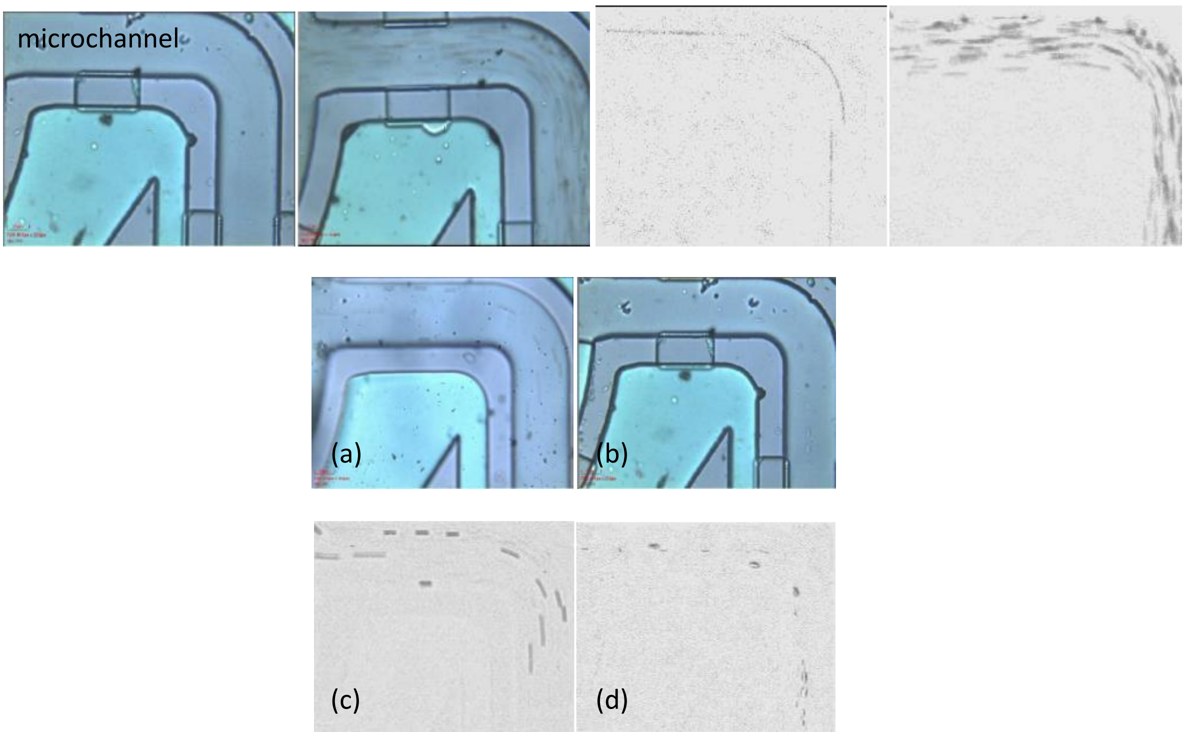

Fig. 3. Flow of polystyrene bead solution through the microchannel at different flow rates set up by coating the pumping material with different agarose gel concentrations. Particle trajectory is visualized via subtracting image background using ImageJ software, (a) Uncoated Wicking substrate, (b) Wicking substrate + 1% gel, (c) Wicking substrate + 5% gel and (d) Wicking substrate + 10%

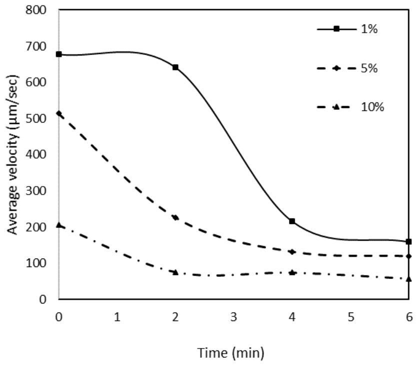

Fig. 4. Effect of gel concentration on solution flow

Conclusion

The presented concept can be used to vary flow rates passively for microfluidics device application. Use of wicking material facilitates the spontaneous liquid flow through microchannels. The change in dimensions and surface energies of the wicking materials results in a wide variation in liquid flow characteristics. Flow rate increases with increased surface area of the material. Change in the surface coatings and pore area also affects the liquid flow. The liquid flow is observed to decrease with higher concentrations of the Agarose polymer coatings.

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References

1. Martinez AW, Phillips ST, Whitesides GM, Carrilho E. Diagnostics for the developing world: microfluidic paper-based analytical devices. Analytical chemistry. 2009 Dec 9;82(1): 3-10.
2. Li X, Ballerini DR, Shen W. A perspective on paper-based microfluidics: current status and future trends. Biomicrofluidics. 2012 Mar 1; 6(1): 011301.
3. Yetisen AK, Akram MS, Lowe CR. Paper-based microfluidic point-of-care diagnostic devices. Lab on a Chip 2013; 13(12): 2210-51.
4. Lewis GG, DiTucci MJ, Phillips ST. Quantifying Analytes in Paper-Based Microfluidic Devices Without Using External Electronic Readers. Angewandte Chemie International Edition. 2012 Dec 14;51(51):12707-10.
5. Du X, Zhao TS, Luo J. Continuous micro liquid delivery by evaporation on a gradient-capillary microstructure surface. Journal of Micromechanics and Microengineering. 2011 Jul 29; 21(9): 095004.
6. Shin JH, Park J, Park JK. Pressure-modulated flow control in paper-based microfluidic devices.
7. Jang I, Song S. Facile and precise flow control for a paper-based microfluidic device through varying paper permeability. Lab on a Chip. 2015; 15(16): 3405-12.
8. Song H, Tice JD, Ismagilov RF. A microfluidic system for controlling reaction networks in time. Angewandte Chemie. 2003 Feb 17; 115(7): 792-796.